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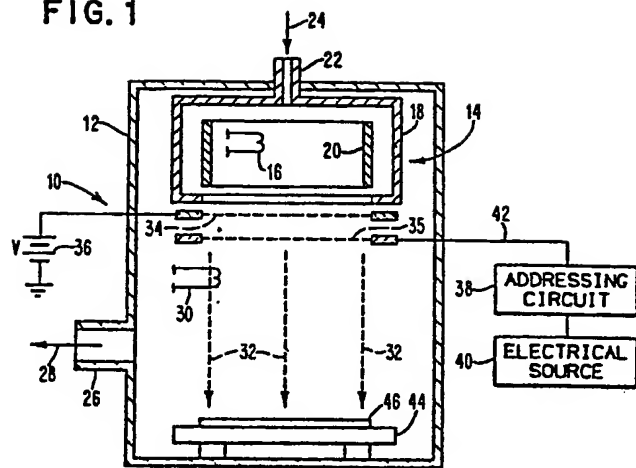
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(54) Programmable ion beam patterning system.

(57) The present invention provides an ion beam system which produces an ion beam pattern without the need for a mask. A programmable grid (35) is used in combination with an ion beam source (14), where the apertures (54, 56, 68) of the programmable grid (35) can have electrical potentials associated therewith which either extract ions or impede the movement of ions through the apertures (54, 56, 68). Depending upon the electrical biasing provided to each of the apertures (54, 56, 68) of the grid (35), different patterns of ions can be extracted through the grid (35). By changing the electrical bias at different locations on the programmable grid (35), these different patterns are produced. The patterns can be used for many applications including patterned deposition, patterned etching and patterned treatment of surfaces.

FIG. 1



PROGRAMMABLE ION BEAM PATTERNING SYSTEM

This invention relates to an ion beam system, for directing an ion beam towards a substrate, comprising an ion source for producing ions and an extraction grid having therein a plurality of extraction apertures for extracting therethrough ions from the ion source to produce the ion beam.

The ion beam system of the present invention can be used for etching, deposition, or surface treatment of substrates without the need for a mask, using an electrically "programmed" extraction grid to pattern the ion beam.

Ion beam sources are used for many applications, including deposition of materials onto substrates, etching of semiconducting and insulating materials, and surface treatment of materials (for purposes such as cleaning).

The etching processes include ion milling and reactive ion beam etching. Each of these types of etching has different advantages, as is known in the art. Depending upon the type of etching required, the ions can be either reactive or nonreactive with the materials they strike.

In ion beam deposition, the ion beam strikes a target in order to release atoms therefrom, which then travel to substrates whereon the atoms nucleate. This type of operation often requires a focused ion beam of sufficient current energy in order to release target atoms at a practical rate.

Whether the ion beams are used for etching or for deposition, the ion beam source typically includes one or more grids to provide the ion beam. The use of these grids allows the production of ion beams of different energies, and different focusing, so that the ion beam can be tailored to the desired application. For example,

US-A-4 259 145 (Harper) discloses the use of a single extraction grid having multiple apertures in order to obtain high current densities at low ion energies for use in reactive ion etching. The Harper patent also
5 includes a discussion of known ion sources which use a pair of grids for extracting an ion beam from the ion source.

The Harper patent describes a disadvantage in the use of a pair of grids (i.e. a screen grid and an
10 extraction grid) in that a shielding effect occurs which reduces the maximum ion current which can be extracted.

The invention described in the Harper patent overcomes this disadvantage by using the plasma sheath
15 between the plasma and a single grid as a screen grid in order to extract a collimated beam of ions. Several advantages for this system are described including ease of manufacturing and low cost, the use of low energy ions in the beam to minimize physical sputtering, and the availability of a high current density of ions in
20 the beam.

In all presently known ion beam systems, the pattern to be deposited or etched is produced through the use of one or more masks, which are in the form of photo-resistor mechanical masks located in the vacuum chamber
25 housing the ion beam source. Depending upon the type of mask used, different patterns of deposition or etching can be produced. If desired, a mask can also be used for surface treatment applications in order to surface-treat specific areas of material, rather than surface-treating
30 the entire area of the material.

While masks have been used effectively to provide patterned deposition, etching, or surface treatment, the need for masks is not without disadvantages. For example, if a series of patterns must be provided, a
35 number of individual masks have to be used in series,

which means that the vacuum in the chamber must be broken a number of times in order to allow the mask to be changed. This is disadvantageous since contamination can occur and it is time consuming. In addition to these problems, effects such as uneven etching (trenching) as well as problems associated with the often difficult removal, replacement and alignment of masks occur.

Another problem associated with the requirement for masks for providing patterns is that processes such as in-line wafer processing become more difficult. In this type of processing, the wafer is brought below a series of masks so that multiple treatment steps can be undertaken. When masks have to be continually removed and replaced, in-line processing is impeded.

According to the present invention, there is provided an ion beam system of the type described above which includes an electrical bias means for electrically biasing individual ones of the extraction apertures to enable selective extraction or prevention of extraction of ions from the ion source through the extraction apertures and thereby to produce a patterned ion beam.

It is an advantage of this system that the need for a mask is eliminated, whether the ion beam is used for deposition, etching or surface treatment. This eliminates the problems generally associated with the use of masks to provide ion beam patterns.

Preferably, the system includes addressing means connected to the electrical bias means for changing the electrical bias on individual ones of the extraction apertures whereby the pattern of the ion beam is programmable.

By use of a 'programmable' extraction grid, it is possible to change the pattern of the ion beam electrically, thereby eliminating the necessity for breaking the vacuum in a vacuum chamber in order to carry out a number

of operations on a substrate with different ion beam patterns, and the need for providing a number of different masks.

5 The system using a 'programmable' extraction grid can be used for multi-wafer processing and for personalization of patterns on wafers on a real-time basis.

The present invention can be used with ion sources which produce positive or negative ions.

10 If desired, the ion beam system may include a screen grid, located between the extraction grid and the ion source, the screen grid being biased to extract ions therethrough and provide a collimated ion beam to the extraction grid.

15 Preferably, the extraction grid comprises an insulating layer having apertures therein and the electrical bias means includes a patterned conductive layer on the insulating layer for producing electric potential at those apertures through which ions are to be extracted.

20 Conveniently, the ion beam source comprises a means for producing a plasma, which is advantageously located in a vacuum chamber.

25 The present invention also provides a process for treating a substrate with a patterned ion beam comprising the steps of:

locating the substrate in an ion beam system of the invention;

30 biasing the extraction grid so that selected ones of the apertures extract or prevent extraction of ions from the ion source; and

causing the patterned ion beam exiting from the extraction grid to impinge on the substrate.

35 The preferred ion beam system of the invention uses an electrically programmable, or changeable, grid for either extracting ions or preventing them from being

extracted from the plasma within the ion source.
Individual electrical control is provided around each
aperture of the grid, or around groups of apertures, in
order to control the locations at which ions pass through
5 the apertures to the surface which the ions strike.
Since individual apertures in the grid can be electri-
cally controlled, the ion beam which is produced is
itself patterned. This eliminates the need for masks
to convert a broad uniform ion beam to a patterned ion
10 beam.

The ion beam system of this invention can use a
screen grid for providing collimated ions to the pro-
grammable grid which produces the actual ion pattern.
In another embodiment, the screen grid is eliminated and
15 the programmable grid is itself used for extraction and
acceleration of the ions which form the ion beam pattern.

Provision of a programmable, or controllable, grid
can be adapted into anytype of ion beam system, such
as those described by H.R. Kaufman et al, J. Vac. Sci.
20 Technol., 21 (3), page 725, September/October, 1982.
Further, the ion beam system of this invention can be
used for any of the applications described by J. M.E.
Harper et al, ibid, page 737. As an example, a multiple
aperture ion source of the type described in aforementioned
25 US-A-4 259 145 can be equipped with an extraction grid
having individually addressed conducting elements around
each extraction aperture of the extraction grid. When
a grid aperture is allowed to float electrically, ions
will not pass through that aperture while, when the
30 aperture is biased to a negative voltage, positive ions
will be extracted through that aperture. Therefore,
by controlling the entire pattern of voltages to be
applied to the apertures of the extraction grid, a
particular pattern of ions will be extracted. This
35 pattern can be electrically changed in accordance with

the fabrication process being undertaken.

In the practice of this invention in its preferred form, a control grid of a particular type is used in any type of ion beam system in order to provide a
5 patterned ion beam without the need for masks to provide a pattern. This type of grid will be termed a "programmable" extraction grid, since it can be electrically changed at various locations of the grid to either extract ions from an ion plasma, or prevent the extraction of these
10 ions from the ion plasma. Depending upon the electrical biasing of the various apertures in this programmable grid, any pattern of ions can be created.

Two embodiments of the ion beam system of the present invention are now described, by way of example only, with reference to
15 the accompanying drawings, in which:

FIG. 1 is a schematic illustration of the first embodiment of the ion beam system of the present invention, having a screen grid and a programmable extraction grid to provide a patterned beam of ions;

20 FIG. 2 is a schematic illustration of a portion of the structure shown in FIG. 1, and illustrates how selective biasing of the apertures in the programmable extraction grid will produce a patterned ion beam;

FIG. 3 is a top view of a portion of the programmable
25 extraction grid shown in FIG. 1, illustrating the conducting patterns which are associated with each of the apertures in the grid, for selectively extracting or preventing the extraction of ions from the plasma, to produce a patterned ion beam; and

30 FIG. 4 schematically illustrates the second embodiment on which was carried out an experiment to establish that a patterned ion beam can be produced with tolerable beam divergence, illustrating that suitable resolution can be obtained using the programmable extraction grid
35 of the present invention.

Referring now to the drawings, FIG. 1 illustrates a multi-grid embodiment of the present invention. In this figure, an ion beam system, generally designated 10,

is used for producing a patterned ion beam within chamber 12 which is, for instance, a conventional vacuum chamber. An ion source 14 is located within the chamber 12, and includes a thermionic cathode 16 located with the walls 18 of the ion source 14. An anode, such as cylindrical anode 20, is also located within the walls 18. While the anode 20 is shown as a cylindrical anode in FIG. 1, it can be the type of anode shown in aforementioned US-A-4 259 145. Inlet port 22 is used to supply a gas to the ion source 14, as indicated by arrow 24. As is well known in the art, the input gas is ionized within the chamber walls 18 to provide an ion plasma.

The chamber 12 is provided with an outlet port 26 which can be used to remove volatile gasses, etc. from the chamber 12, as indicated by arrow 28. Also located within the chamber 12 is a neutralizer filament 30, which is used to provide electrons to compensate the positive charge of the ions in the patterned ion beam, represented by arrows 32. Such neutralizing electrons are particularly useful if the substrates to be subjected to the ion beams are insulating wafers. This type of neutralizing operation and the general structure of the total ion beam system 10 are well known in the art.

A screen grid 34 is used to extract ions from the ion plasma formed within the chamber walls 18. This screen grid will also cause some acceleration of the ions and will provide collimation of the ions prior to their arrival at programmable grid 35. Grid 34 is typically at a voltage V provided by source 36. Programmable grid 35 is provided with voltages at each of its apertures, in accordance with signals provided to selected apertures via addressing circuit 38, which is connected to electrical source 40. In FIG 1, the various connections to the programmable grid 35 are

generally indicated by conductor 42. In practice, the addressing circuit 38 can be any circuit well known in the art for providing signals to x-y conductors such as those typically used in memory circuits. If desired, a computer can provide the electrical signals on the various x-y conductors of the programmable grid 35. The actual physical structure of the programmable grid 35 and the electrical connections adjacent each of the apertures therein will be more apparent from FIGS. 2 and 3.

10 A holder 44 is located within the chamber walls 12, and is used to hold substrates 46 which are to be struck by the patterned ion beam 32. Rather than requiring a masking layer over substrates 46, the present invention provides a patterned ion beam which can be used to surface
15 treat, etch, or deposit onto selected locations of the substrate 46.

In operation, heating current is applied to the thermionic cathode 16 to create free electrons. A discharge voltage between the cathode 16 and the anode 20 is applied at about 50-100 volts. A gas, such as argon, CF_4 , N_2 or O_2 , is applied through the input port 22. Electrons emitted from the cathode 16 are accelerated to the anode 20 by the discharge voltage, and strike the gas atoms within the chamber walls 18. This creates an ion plasma within the walls 18. These positive ions are accelerated from the discharge chamber by a high voltage (typically 500-1000 V) applied between the anode 20 and ground. The ions are extracted by the screen grid 34, and, depending upon the potentials applied to the individual apertures in the programmable grid 35, are either retained in the plasma or extracted from it to produce the patterned ion beam 32.

It will be understood by those of skill in the art that the particular structure of the ion source 14 and the electrical biases applied to the various components

thereof can be changed from that shown in FIG. 1, in order to be able to provide the plasma ions and electrons in the chamber 18.

5 The screen grid 34 is a type of grid known in the art, such as that described in aforementioned US-A-4 259 145. The material used to fabricate the screen grid 34 is an electrically conducting material, such as a metal or graphite. Generally, pyrolytic graphite is preferred, since this material has a low erosion rate and will not
10 be worn away readily by the ions which strike it. Other suitable materials are conducting refractory materials having high melting points which are able to withstand the high temperatures and high energies of the ion beam. Also, silicon grids, which can be fabricated by micro-
15 electronic techniques, can be used.

The programmable extraction grid 35 includes a plurality of current carrying conductors associated with the apertures therein. It is generally comprised of an insulating material having a conductive pattern thereon,
20 as will be more clearly evident in FIGS. 2 and 3. The important feature is that conductor patterns are associated with individual apertures, or groups of apertures, and are electrically insulated from one another so that different potentials can be applied to different
25 locations of the grid 35.

While FIG. 1 illustrates a dual-grid system, it should be understood that the screen grid 34 can be omitted, and its function provided by the programmable grid 35. In a typical example of a dual-grid system, the anode 20 has a bias of approximately 500 volts
30 above ground, while the cathode 16 is approximately 50 volts negative with respect to the anode 20. The housing 16 is grounded and the screen grid 34 has a bias of approximately the cathode potential (i.e. 450 volts).
35 The programmable grid 35 has different voltages at

different apertures therein to either extract ions from, or prevent ion from leaving, the plasma. In order to extract ions, a negative voltage of approximately -100 volts is applied to selected apertures while, to
5 prevent the extraction of ions, the apertures are allowed to float electrically to the ion potential of the plasma.

If the screen grid 34 is omitted and only the programmable grid 35 used, the electrical potentials applied to the ion beam system can be approximately the same as
10 those described in the previous paragraph. However, a single-grid system is generally used for providing low energy beams. For this purpose, lower voltages will be used since a single-grid system provides more extracted ions at low voltage than does a dual-grid system.

15 FIG. 2 illustrates the operation of the programmable grid 35. The purpose of this grid is to selectively determine where ions are to be extracted from the plasma 48, or retained in the plasma, in order to produce the patterned ion beam 32. In this figure, the screen grid
20 34 includes apertures 50 and 52, while the programmable grid 35 includes aligned apertures 54 and 56. Surrounding the aperture 54 is a conductor pattern 58, while conductor pattern 60 surrounds the aperture 56.

In operation, it is desired to extract ions from
25 plasma 48 through aperture 56, but to prevent ions from passing through aperture 54. Therefore a negative bias of approximately -100 volts is applied to the conductor pattern 60 via source 62, while the conductor pattern 58 is unconnected to voltage source 64, as shown in
30 FIG. 2. This means that the conductor pattern 58 will float to the ion potential, and no ions will be extracted through the aperture 54. On the other hand, an ion beam 32 will be extracted through the aperture 56 due to the negative potential applied to the conductor pattern
35 60.

In FIG. 2, the programmable grid 35 is comprised of a layer 66 of an insulating material, such as silicon or glass, onto which the conductor patterns 58 and 60 have been deposited by techniques such as sputtering and/or evaporation. These techniques are well known in the art and can be used to provide patterns of very high resolution. The aperture size in the grid 35 is limited by the resolution of the process used to define the apertures and the conducting patterns 58 and 60. Typically, aperture sizes of about 1 mm to 5 mm or less are used. In a dual-grid system, the size of the apertures is of the order of the spacing between the screen grid 34 and the programmable grid 35. If the screen grid is omitted in the ion system, the aperture size in the programmable grid can be a factor of 5 - 10 times smaller. Micron size apertures are within the range that can be provided by existing fabrication techniques.

In practice, the potentials applied to the conducting patterns 58 and 60 can be rapidly switched, in times such as microseconds, in order to change the pattern of ions extracted from the plasma. Since the patterns can be electrically programmed, the need for multiple masks to provide different ion beam patterns will be eliminated.

In a dual-grid system of the type shown in FIG. 1, the distance between the screen grid 34 and the programmable grid 35 is generally a few millimeters, as is customarily used between screen grids and accelerator grids in prior art ion beam systems. The distance between the programmable grid 35 and the substrate 46 on which the patterned ion beam is to be incident typically ranges from a few millimeters to tens of centimeters. This distance is determined by the divergence (angular spread) of the individual beamlets 32 exiting the grid 35. This spacing is generally chosen in accordance with

the energy of the ions and the resolution which is required.

FIG. 3 is a top view of the programmable grid 35, illustrating the pattern of conductors around each of the apertures in the grid. For the purposes of relating FIG. 3 to the side view of FIG. 2, the apertures 54, 56 are indicated, as well as the associated conducting patterns 58 and 60. Other apertures 68 are also indicated, as are other conducting patterns 70. When a voltage is applied to any of the conducting patterns, those patterns will electrostatically carry a negative potential which will extract ions from the plasma. When no voltage is applied to the conducting patterns, the patterns will float to the ion potential and ions will not be extracted through the apertures. The voltages on any of the conducting patterns, such as 58 and 60, are applied to the associated electrical conductors using the addressing circuits 38 and electrical source 40 shown in FIG. 1. Conventional x-y addressing schemes can be used to select the patterns of ions extracted from grid 35.

FIG. 4 schematically illustrates the second embodiment of the invention which was used to demonstrate the resolution of the ion beam patterns obtainable using a programmable grid. In the apparatus of FIG. 4, a single grid 72 is used as an extraction grid to extract ions from the plasma 74. Grid 72 was fabricated from a silicon wafer and was biased such that argon ions were obtained from plasma 74 at an energy of 200eV. The diameter of the apertures 76 in the grid 72 was about 0.13 mm (0.005 inch). The target of the beam was a copper film 78 located on a silicon substrate 80. The distance between the grid 72 and the top surface of the film 78 was 5 mm.

In this demonstration, all of the apertures 76 of

the grid 72 were biased to extract ions from the plasma 74. This produced individual beamlets 82, 84 and 86. Individual beamlets 82,84,86 produce etched areas 88, 90, and 92 respectively. The size of these etched areas
5 indicate an ion beamlet diversion angle of 0.9 degrees.

In a separate demonstration, the grid 72 was allowed to electrically float to the ion potential (i.e. no voltage was applied to the conducting pattern adjacent grid aperture 76) which prevented the extraction of ions
10 from plasma 74. Thus, a programmable grid of the type described herein can be used to make depositions or etched patterns in a substrate with good resolution, and without the need for multiple masks. The potentials applied to the conducting portions of the programmable
15 grid can be changed rapidly (in microseconds) to rapidly change the pattern of the ion beams impinging upon the substrate.

In the practice of this invention, substrates can be continually moved past an ion beam system including
20 this programmable grid, in order to personalize different substrates with different patterns. As an example, a single line of apertures may be used in the programmable grid, with a plurality of substrates being moved past the grid in order to change the ion beam pattern, depending upon the nature of the substrate in the particular
25 step in the fabrication process.

In the further practice of this invention, it will be apparent to those skilled in the art that any type of ion or charged particle can be used to provide a
30 patterned beam of these charged-particles. The principles of this invention can be applied to either positive or negatively charged ions, atoms, molecules or particles. However, the greatest utility for the present invention will be in ion beam systems utilizing positively charged
35 ions for various processing steps in the fabrication

of microelectronic structures and other thin film structures.

5 Although the invention has been described with respect to particular embodiments thereof, it will be apparent to those skilled in the art that variations can be made therein without departing from the scope and concept of the present invention.

CLAIMS

1. An ion beam system (10), for directing an ion beam (32) towards a substrate (46), comprising:
an ion source (14) for producing ions; and
5 an extraction grid (35) having therein a plurality of extraction apertures (54,56,68) for extracting there-through ions from the ion source (14) to produce the ion beam (32).
characterised in that the system (10) includes:
10 electrical bias means (40,42,58,60,70) for electrically biasing individual ones of the extraction apertures (54,56,68) to enable selective extraction or prevention of extraction of ions from the ion source (14) through the extraction apertures and thereby to produce a patterned
15 ion beam (32).
2. The ion beam system of claim 1, further including:
addressing means (38) connected to the electrical bias means (40,42,58,60,70) for changing the electrical bias on individual ones of the extraction apertures
20 (54,56,68) whereby the pattern of the ion beam (32) is programmable.
3. The ion beam system of claim 1 or claim 2, wherein the ions are positively charged.
4. The ion beam system of claim 1 or claim 2, wherein
25 the ions are negatively charged.
5. The ion beam system of any one of claims 1 to 4, further including:
a screen grid (34), located between the extraction grid (35) and the ion source (14), the screen grid (34)
30 being biased to extract ions therethrough and provide a collimated ion beam to the extraction grid (35).
6. The ion beam system of any one of claims 1 to 5, wherein the extraction grid (35) comprises an insulating layer (66) having apertures (54,56,68) therein, and the
35 electrical bias means includes a patterned conductive layer

(58,60,70) on the insulating layer (66) for producing an electric potential at those apertures through which ions are to be extracted.

5 7. The ion beam system of any one of claims 1 to 6, wherein the ion source (14) comprises means (16,18,20, 22,24) for producing a plasma.

8. The ion beam system of claim 7, wherein the plasma producing means is located in a vacuum chamber (12).

10 9. The ion beam system of any one of claims 1 to 8, further including a substrate (46) onto which the ion beam (32) is incident.

10. A process for treating a substrate with a patterned ion beam comprising the steps of:

15 locating the substrate in an ion beam system according to any one of claims 1 to 8;

biasing the extraction grid so that selected ones of the apertures extract or prevent extraction of ions from the ion source; and

20 causing the patterned ion beam exiting from the extraction grid to impinge on the substrate.

FIG. 1

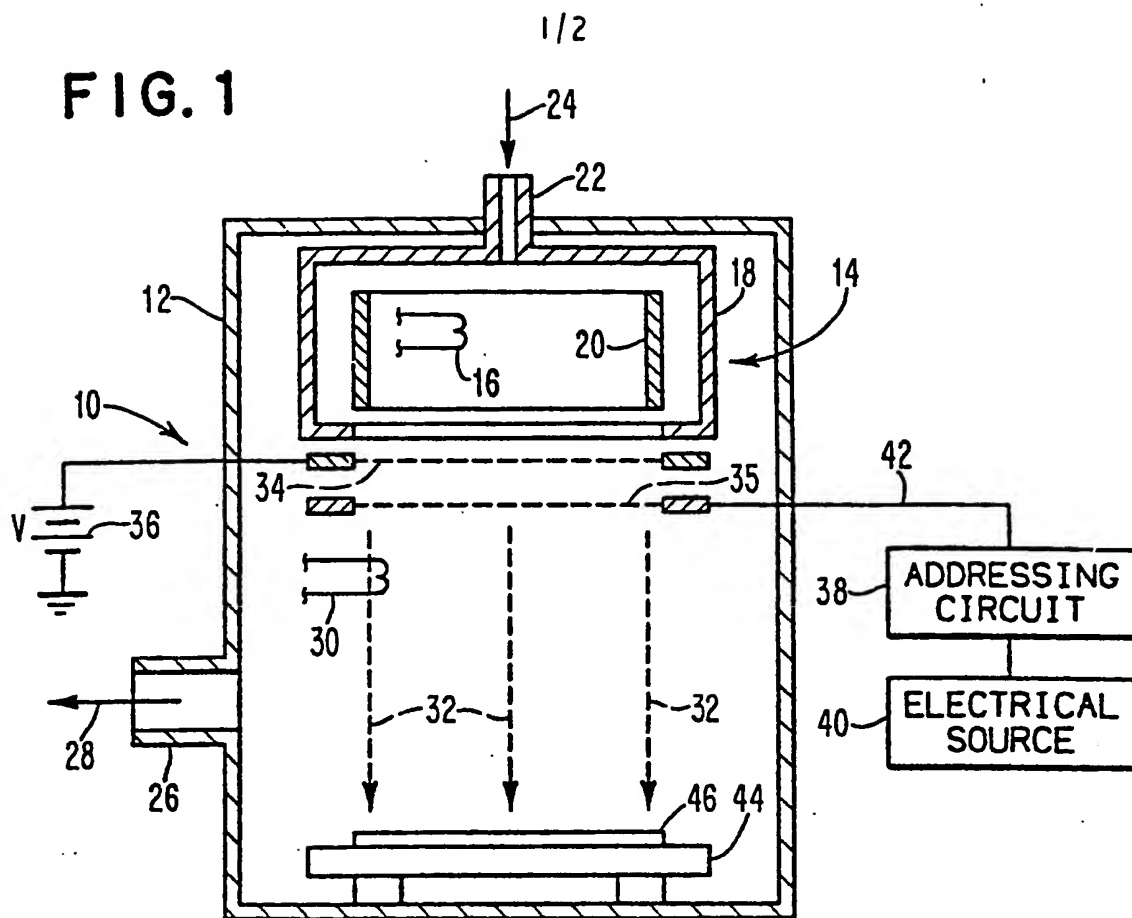
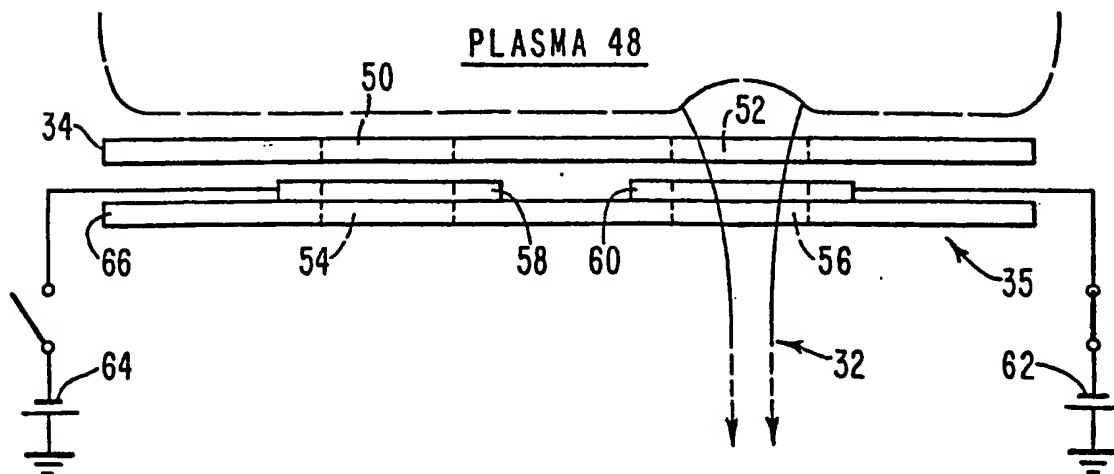
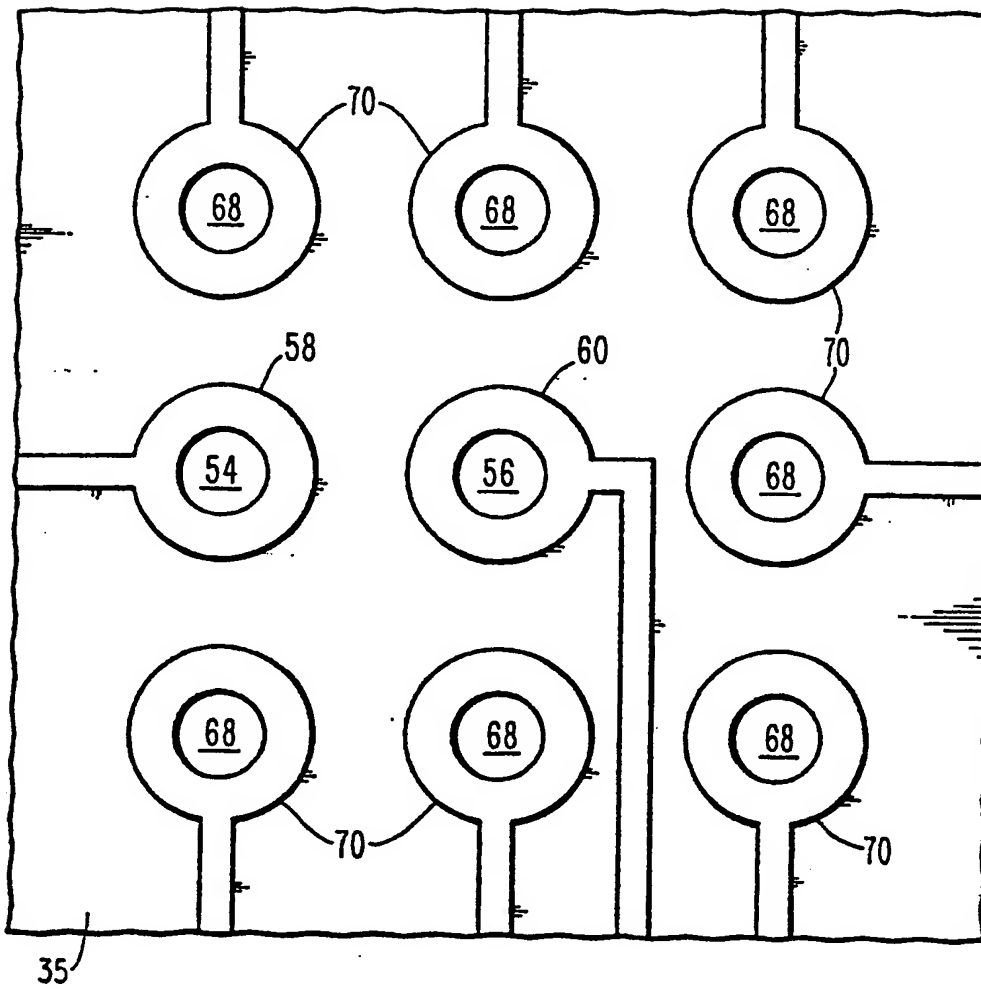


FIG. 2



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FIG 3**FIG. 4**